UNCLASSIFIED

Defense Technical Information Center
Compilation Part Notice

ADP012456

TITLE: A Chatter Box - Investigation of Dynamic Response Across a Gap

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: 10th U.S. Army Gun Dynamics Symposium Proceedings

To order the complete compilation report, use: ADA404787

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012452 thru ADP012488

UNCLASSIFIED

A CHATTER BOX –
INVESTIGATION OF DYNAMIC RESPONSE ACROSS A GAP

10^{TH} U.S. ARMY GUN DYNAMICS SYMPOSIUM

G. Peter O'Hara
Elmhurst Research
60 Loudonville Rd
Albany NY 12204-1513

Virtually all mechanical devices contain several components which are joined or articulated, at joints which must have some clearance. The clearances are required for ease of motion during assembly and/or operation. These clearances produce complex motions when the assembly is subjected to transient motions such as the recoil of a cannon system. This work takes a geometrically simple chatter box system and subjects it to a simple haversine motion using 4 different time frames. The two contact surfaces are given different clearances in an attempt to study one system under a variety of different conditions. The contact stress and the motion of the central slug are shown for all of these 16 cases.

INTRODUCTION

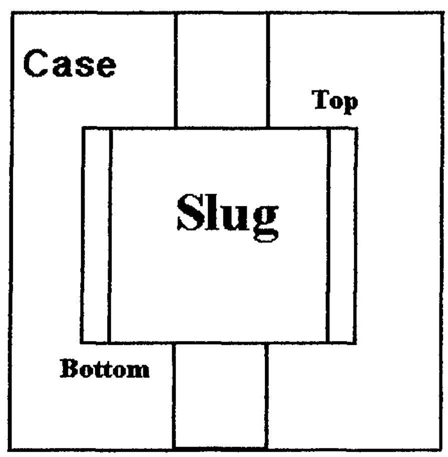
In a previous paper [1] this author reported on the possible catastrophic behavior of a cannon system in response to an adverse (higher speed) loading condition. Further unpublished results tended to support this the early conclusion, for that system. However long experience with cannon systems does not support the notion that this type of problem is common even when very high accelerations are measured on large gun systems. Many modern cannons have rather complex subsystems attached to them such as, muzzle reference devices, firing mechanisms, thermal warnings devices, etc. While the design of these small subsystems is always problematic they never seemed to have, 'show stopping' failures. None the less these small parts occasionally fail and these failures are rarely considered important enough for a detailed failure investigation and frequently go unreported. This author has conjectured that many of these failures are the result of an abnormal and undetected vibration across a gap, that has become a problem due to normal system tolerances combined with everyday wear of the individual components.

In order to gain more insight about this general class of problems, a simple study problem was selected which was small enough to allow a rather large matrix of solutions. The problem selected was the 'Chatter Box' problem which is classically a ball in trapped between two walls. In this case a short cylindrical steel slug was trapped in a one piece case which took the form of a hollow cylinder. This was selected as a first problem which could be extended to a more practical design for an experiment where the hole in the case could allow measurement of the slug motion. A further goal was to produce substantial amplification of the contact stresses similar to the initial practical study.

This is an academic numerical experiment in which the initial design was continued regardless of the result. This design involved the use of four different contact conditions and four different time frames for a total of 16 solutions. These results show the contact conditions and slug motion giving a total of 32 plots of the result. The basic model also includes several elastic body effects that are frequently ignored, such as the distributed mass of the bodies, an array of vibration modes and the non-uniform stress on the contact surfaces. The large number of solutions was intended to form a data base for future reference.

GEOMETRY AND LOADING CONDITION

The problem consists of a solid cylindrical slug with a height and diameter of 25 mm trapped in a case 100 mm long and 100 mm in diameter. This is shown in schematically in Fig. 1 where it can be seen that the slug and case interact at the two ends of the slug and there is a space around the outer diameter of the slug. Because the case is a hollow cylinder, the contact surfaces are in the form rings and the contact conditions at these rings will be one of the primary variables of this report. There are four different contact conditions, the simplest is that the contact surfaces are a perfect fit and are bonded together. This condition simulates a solid structure which permits the contact surfaces to support both tension and compression stress. This condition is not physically realistic but provides a simple reference case. The second condition releases the bonding and provides a surface contact which only supports compression stress, however the initial fit is unrealistically a perfect fit with zero gap. The third condition provides a gap at the top contact surface of 0.00025 mm or 0.001 times the cylinder height. This would be considered a very snug precision fit in any mechanism. The fourth contact condition doubles the gap to 0.0005 mm or about the thickness of a sheet of paper.



Displace this End

Figure 1 - The geometric arrangement of a short cylindrical slug trapped in a solid case with four different contact conditions.

Again referring to figure 1 the loading input will take the form a controlled displacement at the bottom of the case. The form is a single haversine pulse with a height of 10 mm and four different time durations. The first is a gentile pulse with a total time of 0.002 seconds. The times were then decreased to 0.001, 0.0004 and 0.0002 seconds. The 0.0002 time provides an extremely violent motion with a peak acceleration of 100 times the first.

ANALYSIS

The solutions were carried out using the Direct Integration Dynamic analysis included in ABAQUS/ Standard from Hibbit Karlsson and Sorense Inc. [2]. The slug was modeled with 128 second order quadrilateral elements with three elements interacting at the contact surfaces. The case was modeled with 167 elements. This allowed a rather detailed model of the elastic properties of each body without excessively long computer runs for the individual solutions. The haversine was input as a table with 201 individual data points, which provided a reasonable representation of the function. The minimum time step was set to produce a solution with at least 200 times increments and the error tolerance (HALFTOL) was selected to produce a solution in a maximum of about 350 increments. This allowed a rather detailed solution with some errors which take the form of a few contact stresses which became positive.

At this point it should be pointed out that the numeric integration algorithm requires the use of a small damping factor to produce a stable solution. [3] This damping removes the higher vibration frequencies and is is evident in the solutions with longer time frames (0.002 and 0.001 seconds).

RESULTS

The results of the 16 solutions are shown in two different types of graphs. Figures 2, 4 ,6 and 8, are plots of the average contact stress on the bottom and top contact surfaces. Figures 3, 5, 7 and 9. Are plots of the acceleration and displacement of the center of the slug. Each figure contains four graphs a, b, c, and d, which show the data for the four contact conditions at that particular time interval. This arrangement seemed to be the best for the overall evaluation of the various solutions. The four different time frames in this study produce basic stresses which are very different in magnitude so it was decided to nondimensionalized them by the simple average quasistatc stress. This stress was calculated using the peak acceleration of the haversine, the mass of the slug and the total contact area. Using this method all stresses were plotted using the same range of –3.5 to 2.5 on the Y axis. This produces stress plots which are actually plots of stress amplification factors. This concept was extended to the accelerations data which was nondimensionalized to the maximum acceleration of the haversine function. Then all accelerations could be plotted using a Y axis range of –6.0 to 6.0.

The contact stresses were extracted as axial stress in the three elements, of the slug, which form the contact surface. The most accurate stress in an element is calculated at the nine Gaus integration stations and the three nearest the contact surface were selected to represent the contact stress. With three gaus stations in each of three elements there were nine stresses curves to average for each contact surface. This overall average is the data shown in the plots. The contact stress at the bottom surface is plotted as a solid line and the top surface is shown as a dashed line. Note that with a bonded gap the stress at the top is lower than the stress at the bottom. This is because both surfaces support loads and the top is further from the driven surface.

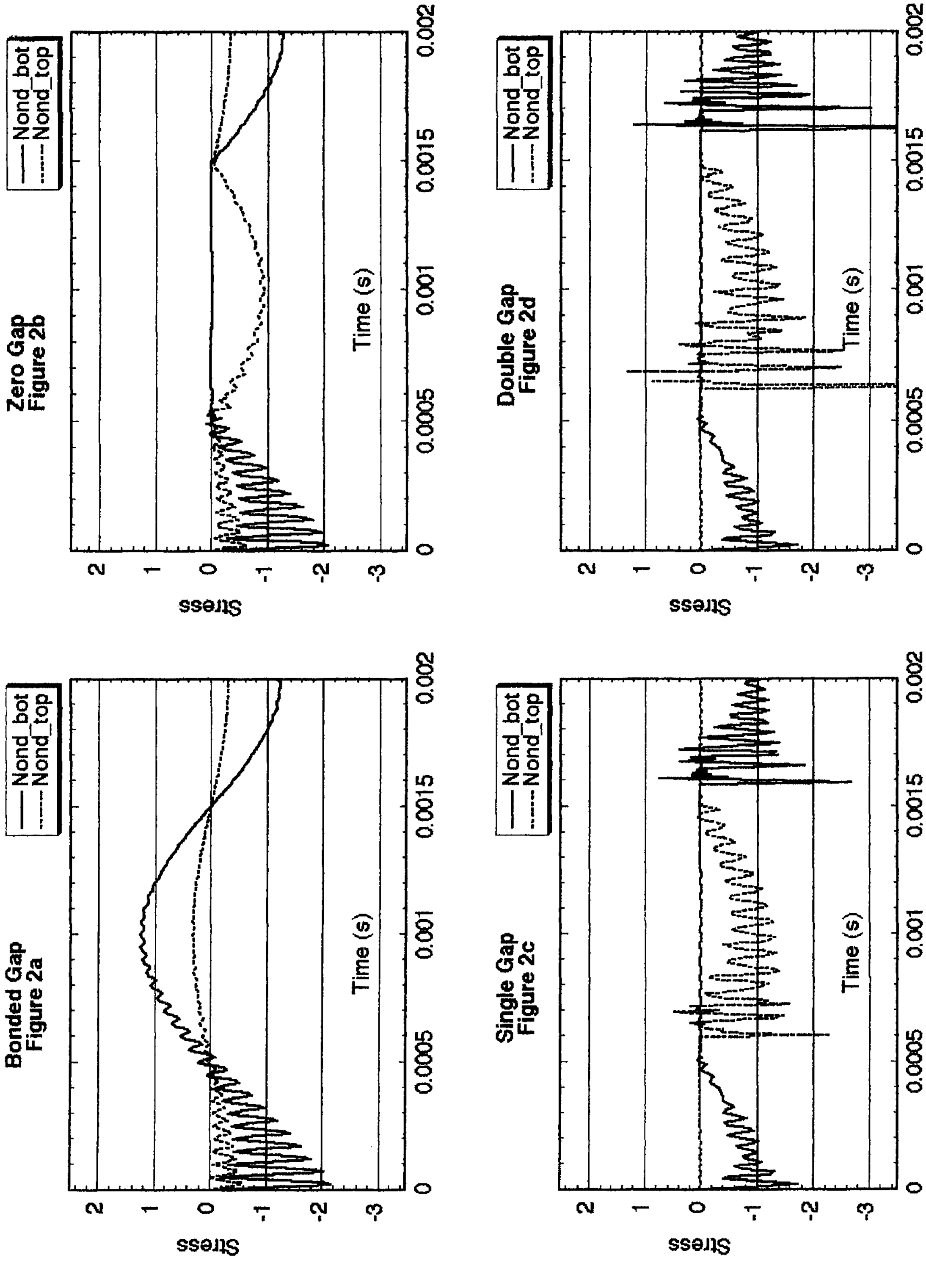


Figure 2 Nondimensional contact stress for four contact conditions and 0.002 seconds total time.

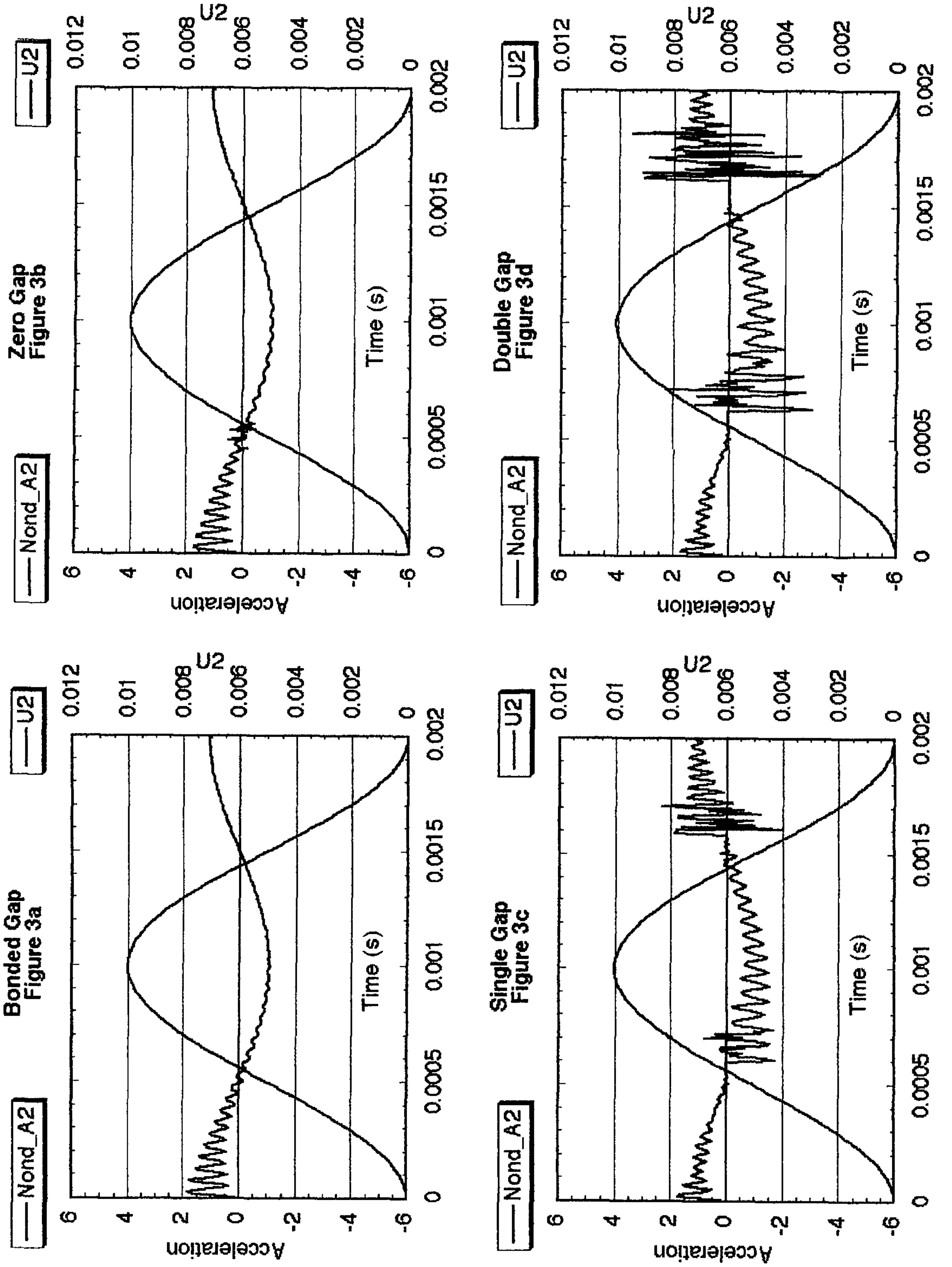


Figure 3 Nondimensional acceleration and displacement for four contact conditions at a total time of 0.002 seconds.

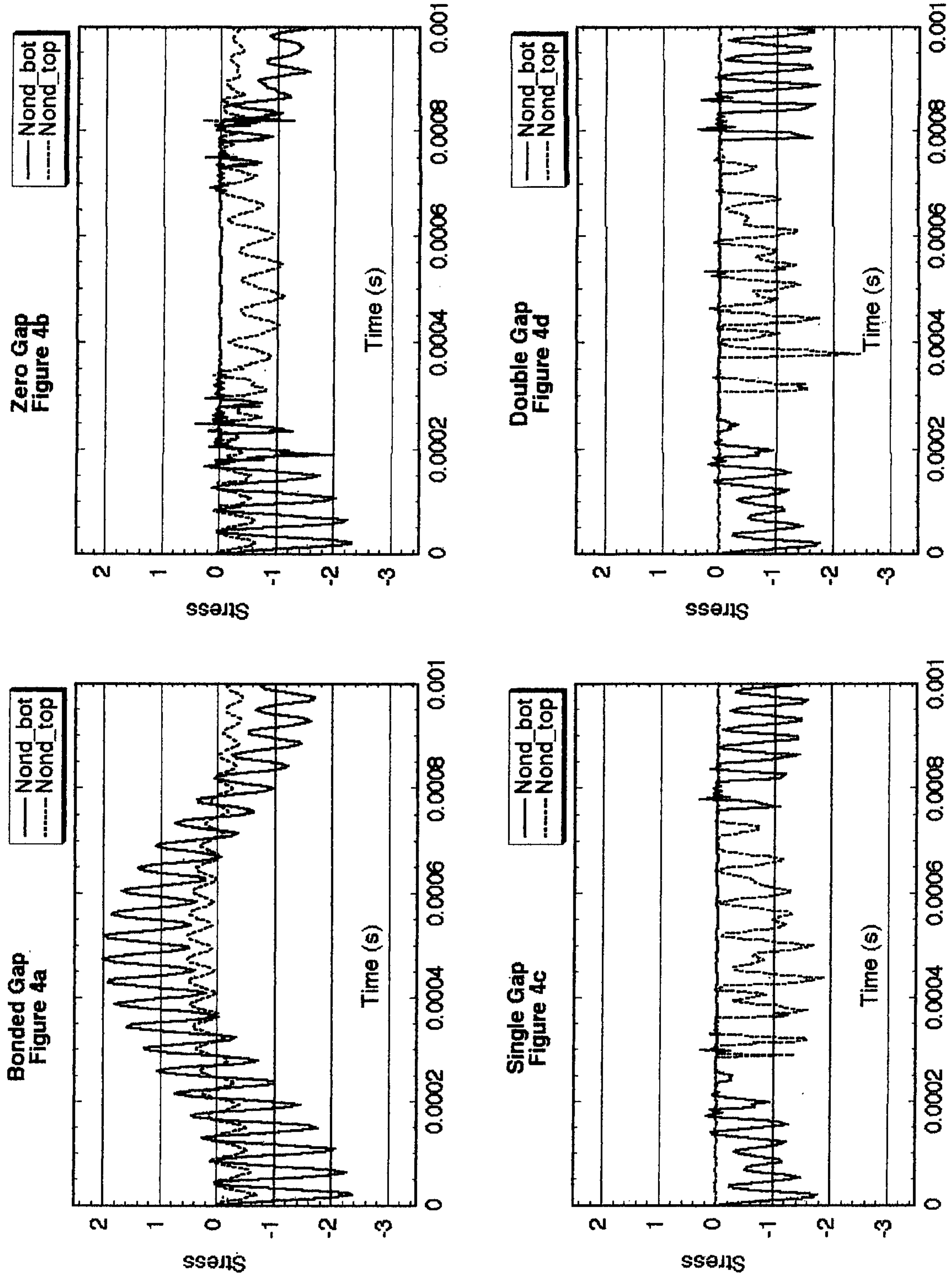


Figure 4 Nondimensional contact stress for four contact conditions and 0.001 seconds total time.

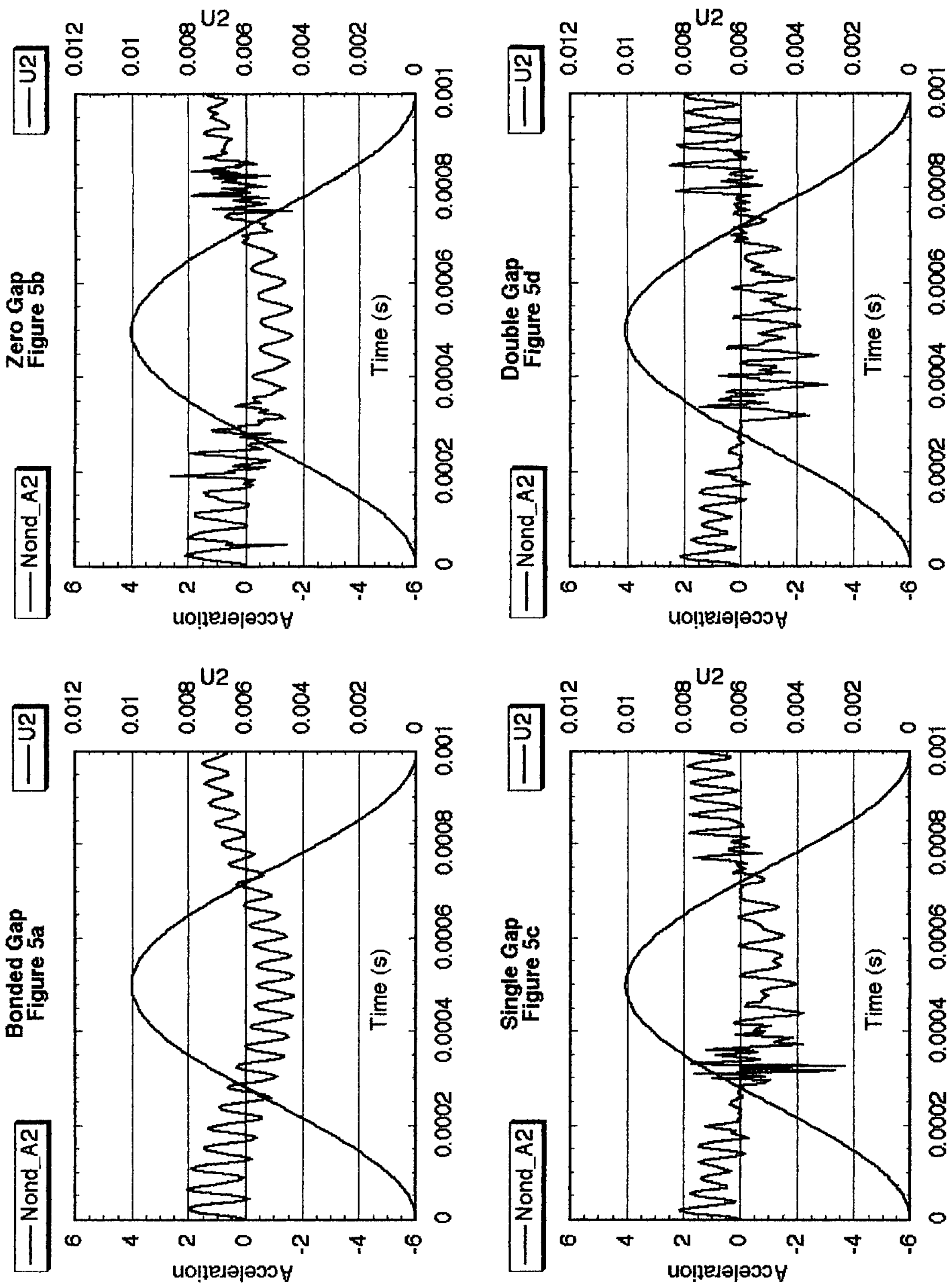


Figure 5 Nondimensional acceleration and displacement for four contact conditions at a total time of 0.001 seconds.

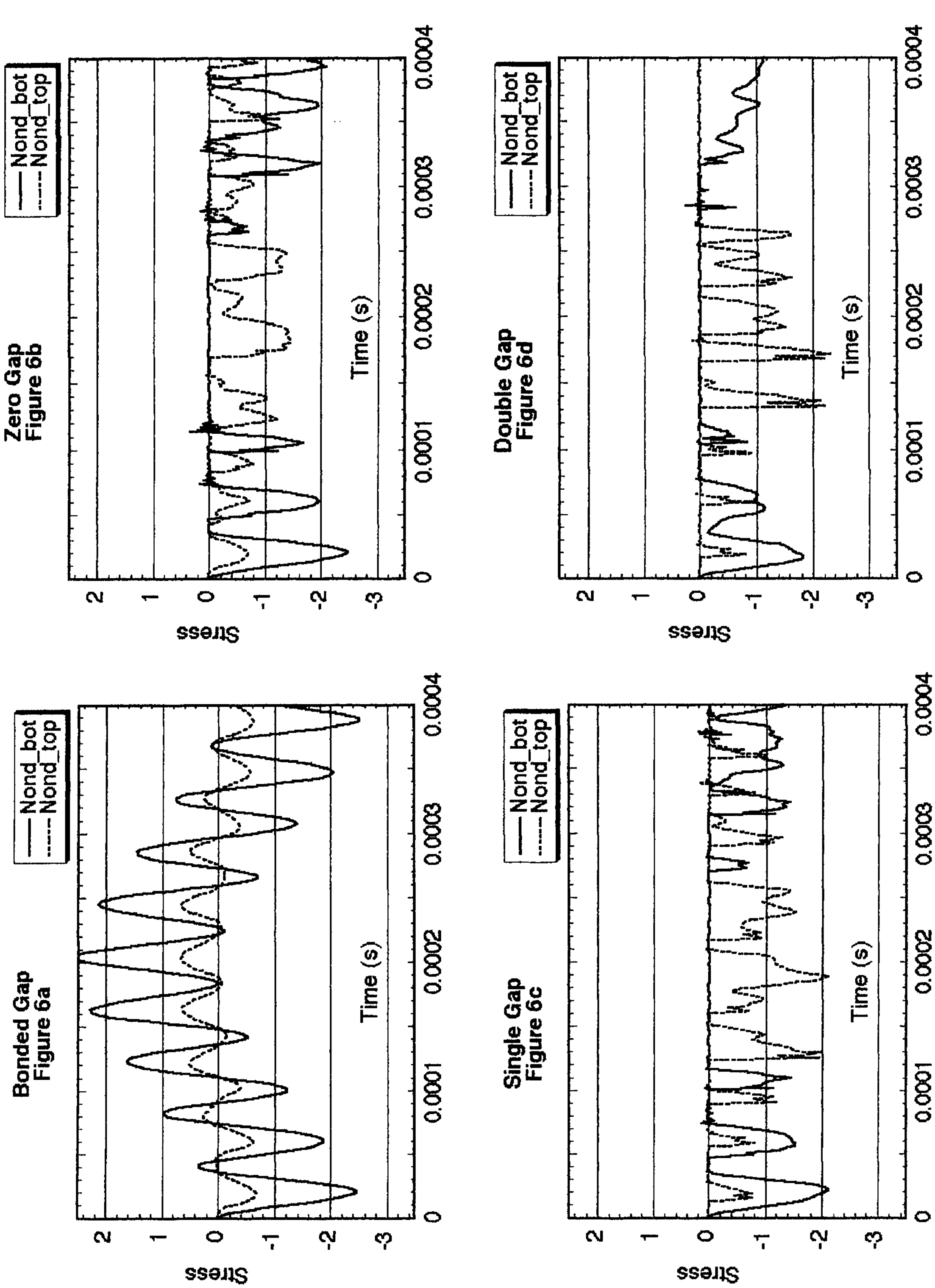


Figure 6 Nondimensional contact stress for four contact conditions and 0.0004 seconds total time.

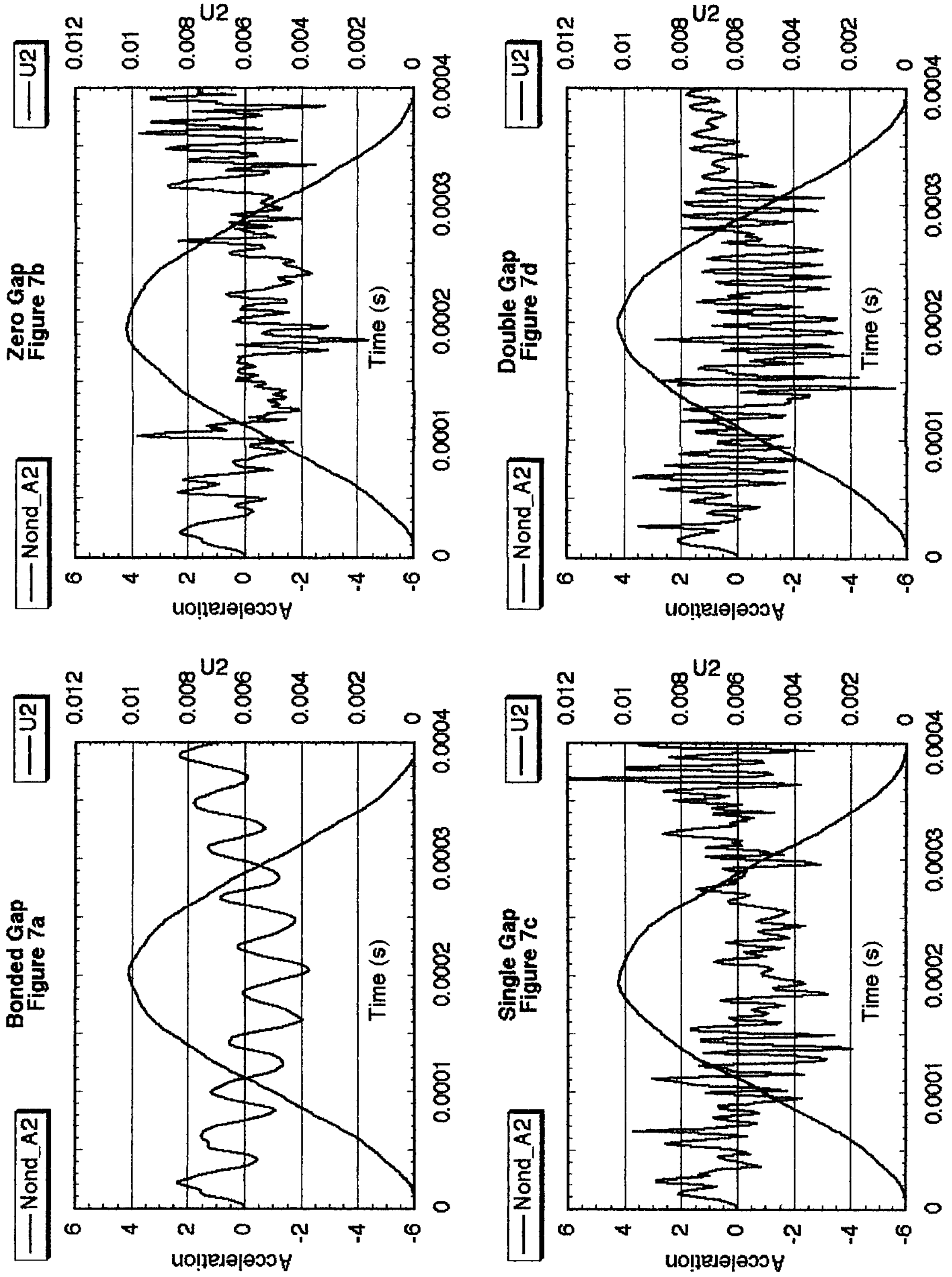


Figure 7 Nondimensional acceleration and displacement for four contact conditions at a total time of 0.0004 seconds.

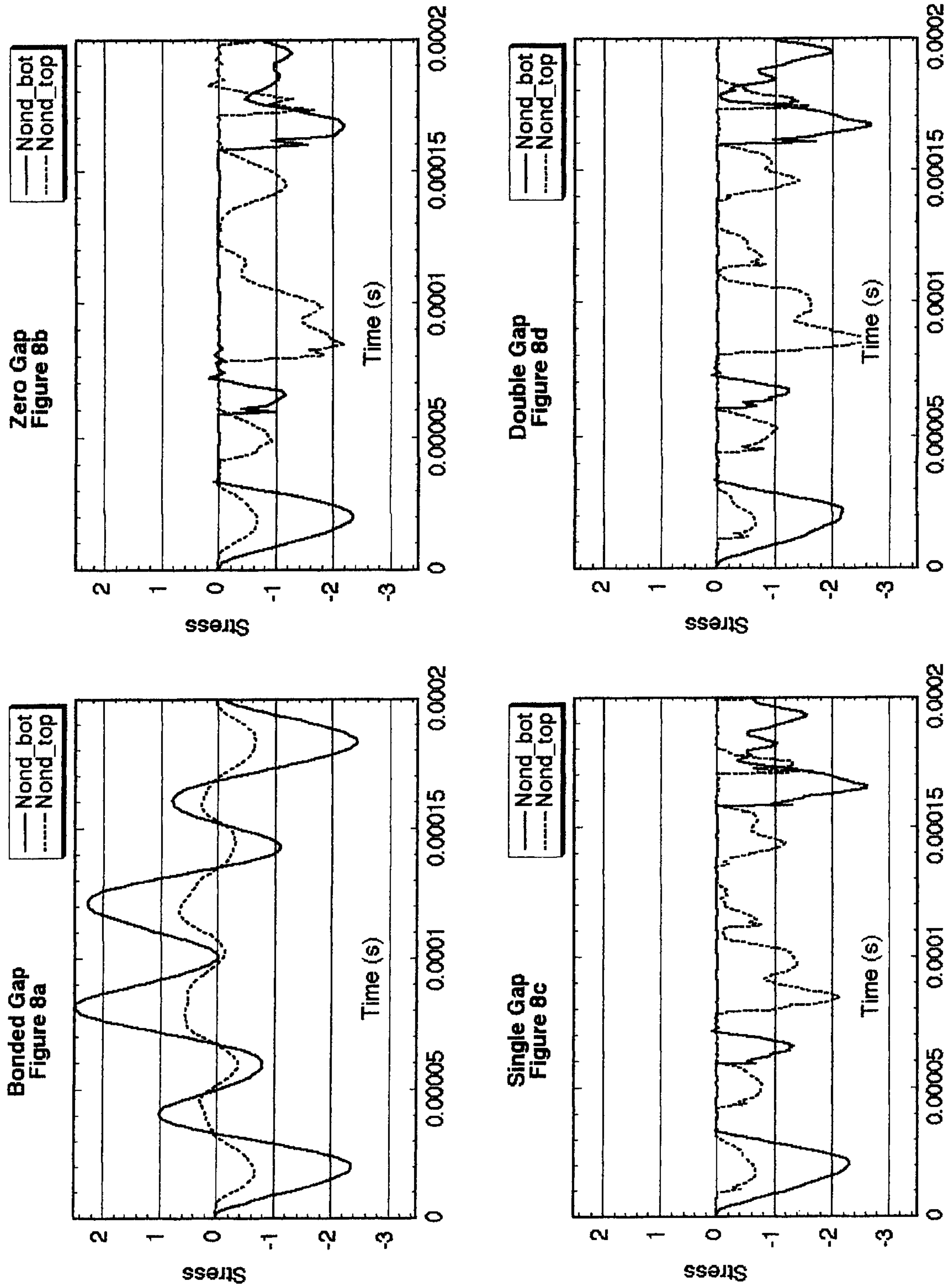


Figure 8 Nondimensional contact stress for four contact conditions and 0.0002 seconds total time.

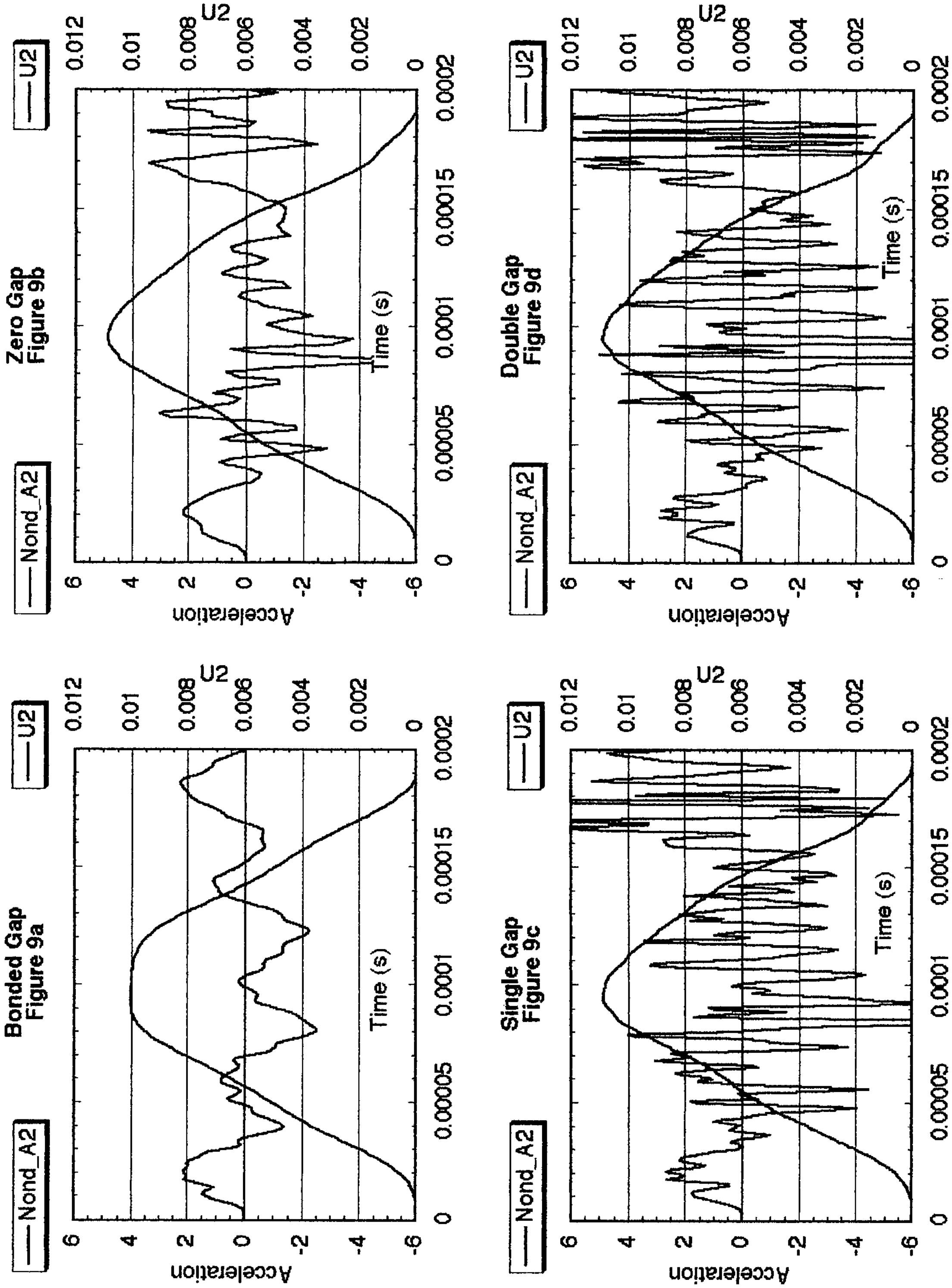


Figure 9 Nondimensional acceleration and displacement for four contact conditions at a total time of 0.0002 seconds.

The plots which show the slug movement each have two curves. First is the displacement of the slug which is nominally has the same maximum value for all cases. The accelerations are nondimensionalized to the maximum acceleration of the Haversine. In this way the acceleration is actually an acceleration amplification factor. Here it should be noted that the displacement curve closely resembles the Haversine at the longer time frames and becomes rather distorted at faster speeds.

DISCUSSON

This study was started as a simple case to explore the behavior of a system that could be set up as a laboratory experiment, However the results are far from simple. The reader can see a variety of behaviors in the 16 solutions, including:

1)The unequal distribution of stress in the bonded cases.

2) The complex multiple impacts of the high speed cases with gaps.

3) The free movement of the slug across the gap.

4) Contact on both surfaces when the gap is zero or small.

5) When the times are long the behavior closely follows the input function.

6) The clear superimposed resonant frequency on the bonded cases.

All of the bonded cases produced the desired result that could be clearly seen and explained. The stresses and movements are a combination of the input haversine plus a small number of resonant frequencies and there is a clear correlation between the slug acceleration and the contact stress. The first resonant frequency is clearly visible in all cases and in the 0.002 second time frame (Fig 2a, and 3a) it is totally damped out by the required numeric damping. In 0.0002 second (Fig 8a and 9a) there are 2 or 3 frequencies visible and damping is not apparent. When the bond is released the behaviors become more complex.

When the bond is released the contact surface no longer supports tension and the slug is free to contact either or both contact surfaces. This adds a strong nonlinear effect to the solution which is apparent at zero gap. First the stress is always compressive and any small tension spikes is the result of numeric error. There also can be contact on both surfaces when the case is in a state of compression. The behaviors are still rather predictable and there remains a good correlation between acceleration and contact stress. The presents of any gap produces two new effects first is the free movement of the slug across the gap and second is the impact of the slug on the new contact surface(Figs 2c and 3c). However the correlation between contact stress and acceleration is present only at the longer time frames and at the shorter time frames the nature of the input function is not apparent from the acceleration or contact stress results. Another effect to note is that the two different gap sizes produce results which are qualitatively similar but strongly different in detail.

The reader should examine the figures closely and draw further information from them and personnel experience. However a review of the mechanics of the basic displacement input function may be useful. The function starts at zero displacement and zero velocity but the acceleration is at the maximum value. The function then forces upward movement to a maximum velocity, at one half of the height and one quarter of the time. The acceleration then reverses in sign and the velocity slows. At one half of the time the displacement is at the maximum, the velocity is zero and the acceleration is again at its maximum value but it has the opposite sign. This process is reversed in the last half of the time as the function returns to its original velocity and position at the full time interval. There is a problem with this approach. At time equal to zero the input function has the acceleration maximum and the two bodies are at rest. This discontinuity is what sets off all initial oscillation in the solutions.

In the description of the applied loads, the 0.002 second haversine is refereed to as a rather gentile input. This is a relative statement, which needs to be clarified. The maximum acceleration is 48,000 meters per second per second or structure, about 5000 g. But in this small size the simple contact stress in only 16.1 mPa which is small when compared to the usual gun steel with a static yield stress of about 1000 mPa. The system also has a first natural frequency, which ranges from 18k to 24k Hz depending on which contact surface is engaged. When the period of the haversine is reduced to 0.0002 seconds the acceleration and simple contact stress increase by a factor of 100 but the natural resonant frequencies do not change and the increase in yield strength is open to question. This brings up the concept that of the importance of size or scale when evaluating the importance of dynamic effects.

The results of this study show that correlation between the contact stress and the acceleration of the slug vary with different time frames. At the longer time frames the correlation is excellent for the bonded and zero gap solutions. However at the shortest interval the correlation is poor in all cases and the single and double gap cases have little correlation at all. With all of this the maximum contact stress usually does not exceed two or three times the simple quasi-static value. This would be within the normal safety factors and would probable only present a failure problem for the most extreme cases. This tend to support the idea that, the presents of the gaps would make the response more complex but may not present sever failure problems.

CONCLUSION

This numeric experiment did not produce the desired result and excessively large contact stresses were not produced. The results show a moderate amplification factor, for contact stress, remarkably close to the 2.0 factor which is given in many undergraduate text books. However the results do become much more complex as the loading speed is increased and the gaps become larger. This tends to support the result which is often seen in the field where the result may be complex but not catastrophic. The acceleration data shows a somewhat different result in which the amplification factor is larger and the signal is also more complex.

ACKNOWLEDGMENTS

The author wishes to thank the management and staff of the U.S. Army Benet Laboratories for the opportunity to complete this investigation and Mr. James Bendick for his support of my work.

REFERENCES

1. G. P. O'Hara, "Dynamic Analysis of a 155 mm Cannon Breech," *Proceedings of the 9 Th. US Army Gun Dynamics Symposium, Mc Lean Vairginia,* , 13-1 – 13-10, Nov. 1998
2. ABAQUS Users Manual Version 5.8, Hibbitt, Karlson & Sorensen Inc. 1080 Main St. Pawtucket RI, 1998
3. ABAQUS Theory Manual Version 5.8, Hibbitt, Karlson & Sorensen Inc. 1080 Main St. Pawtucket RI, 1998, PP 2.4.1-1 – 2.4.1-7